# SSV case 2

*EE4*

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# I. Correction of the Sankey diagram

For the first diagram we used some theoretical parameters, which we can now replace by the experimentally determined values of our SSV. We measured the weight and the frontal area of the car and we calculated the correct Crr. We also got a new solar panel, which means we had to do new measurements for the new diode factor.

## At maximum velocity

### *Start*

The new solar panel has other dimensions, this means we start from another amount of incoming energy.

$$P = 800\,\frac{W}{m^2} * 0{,}180m * 0{,}360m = 51.84W$$

### *Loss of the solar panel*

Using the bisection method we solve the following equation.

$$I = Isc - Is\left(e^{\frac{E+RI}{m*N^{"}*Ur}} - 1\right)$$

With E=4,745 (calculated in the first version of the Sankey diagram)
Isc=0.88A
Is=$10^{-8}$A
m=1,216 (new diode factor)
N=16
Ur=0,0257V
R=3,32Ω

We find I=1,326A

$U = I * R + E = 1{,}326 * 3{,}32 + 4{,}745 = 9{,}147$V

Knowing I and U we can calculate the output power of the solar panel.

$$P_{remaining} = U * I = 1{,}326 * 9{,}147 = 12{,}13W$$

### *Loss of the motor*

The losses in the motor depend on the internal resistance and the current through it. With this information given, we can calculate the power losses in the motor.

$$P = I^2 * R = 1{,}326 * 3{,}32 = 5{,}836W$$
$$P_{remaining} = 6{,}294\ W$$

### Loss air resistance

The first assumption of the frontal area was correct. The $F_{air}$ will be the same as in the first Sankey diagram.

$$Fair = \frac{\rho * A * Cw * v^2}{2} = 0{,}0885$$

$$Ploss\ air = Fair * v = 0{,}327W$$

$$P = 6{,}294 - 0{,}327 = 5{,}967\ W$$

### Loss rolling resistance and transmission

For determining the rolling resistance of the car, we placed the SSV on top of the race track, and let it roll down the hill. It rolled 12 m. By using law of conservation of energy we calculated the rolling resistance. The potential energy on top of the hill is equal to the energy that the car loses because of the rolling resistance, the friction and the air resistance.

The velocity used in this calculation is the average velocity during the rolling down on the track.

$$m \cdot g \cdot h = (m \cdot g \cdot Crr \cdot x) + \frac{\rho \cdot A \cdot Cw \cdot v^2}{2} \cdot x$$

$$0{,}800 \cdot 9{,}81 \cdot 0{,}5 = (0{,}800 \cdot 9{,}81 \cdot Crr \cdot x) + \frac{1{,}293 \cdot 0{,}2 \cdot 0{,}5 \cdot 1{,}09^2}{2} \cdot x$$

$$3{,}92 = (0{,}800 \cdot 9{,}81 \cdot Crr \cdot 12)$$

$$Crr = 0{,}038$$

This value for Crr also contains the friction of the transmission. The power losses due to this Crr are:

$$P = m \cdot g \cdot Crr \cdot v = 1{,}10\ W$$
$$P_{remaining} = 5{,}867\ W$$

## At half of the maximum velocity (on slope)

### Start

The new solar panel has other dimensions, this means we start from another value.

$$P = 800\ \frac{W}{m^2} \cdot 0{,}180m \cdot 0{,}360m = 51.84W$$

### Loss of the solar panel

Using the bisection method we solve the following equation.

$$I = Isc - Is\left(e^{\frac{E+RI}{m*N^{"}*Ur}} - 1\right)$$

With E=3,954 (calculation see first Sankey diagram)

Isc=0.88A

Is=$10^{-8}$A

m=1,216 (new diode factor)

N=16

Ur=0,0257V

R=3,32Ω

We find I=1,564A

$U = I \cdot R + E = 1{,}326 \cdot 3{,}32 + 3.954 = 9{,}147\text{V}$

Knowing I and U we can calculate the power that the solar panel gives.

$$P = U \cdot I = 1{,}564 \cdot 9{,}147 = 14{,}306W$$

## Loss of the motor

$$P = I^2 \cdot R = 1{,}564 \cdot 3{,}32 = 8{,}122W$$
$$P_{remaining} = 6{,}184\ W$$

## Loss air resistance

$$Fair = \frac{\rho \cdot A \cdot Cw \cdot v^2}{2} = 0{,}0221$$

$$Ploss\ air = Fair \cdot v = 0{,}041W$$

$$P_{remaining} = 6{,}184 - 0{,}041 = 6{,}143\ W$$

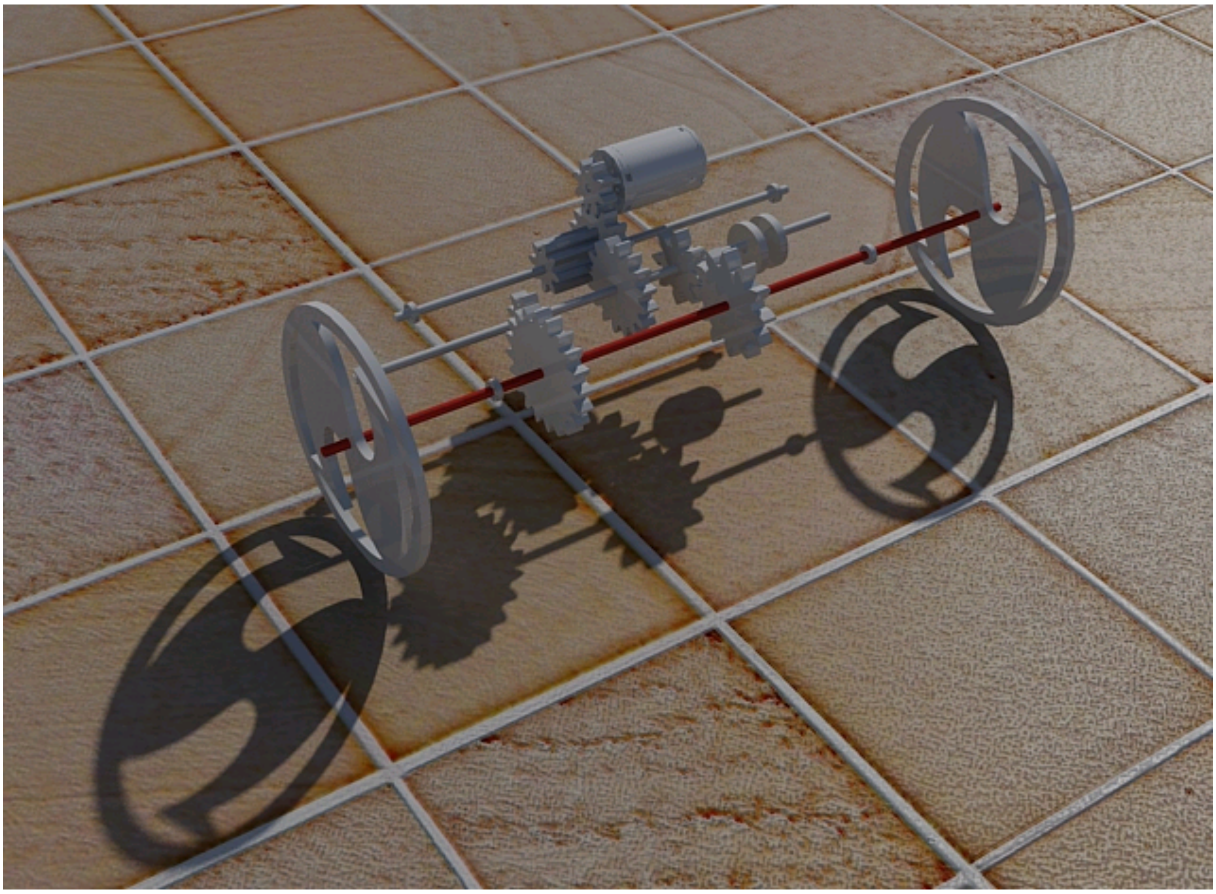
## Loss rolling resistance and transmission

$$P_{remaining} = 6{,}143 - m \cdot g \cdot Crr \cdot v = 5{,}63\ W$$

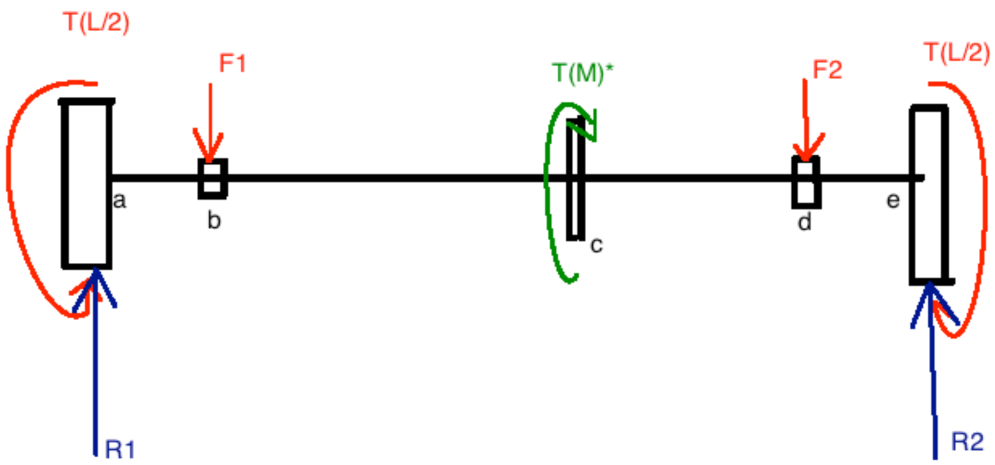
## Loss slope

$$\mathrm{F} = \sin\left(\arctan\left(\frac{1}{8}\right)\right) \cdot 0{,}8 \cdot 9{,}81 \cdot 1{,}85 = 1{,}801$$
$$P = 1{,}801 \cdot 1{,}85 = 3{,}33\ W$$
$$P_{remaining} = 2{,}3\ W$$

## II. Analysis of the drive shaft



*This is a 3D drawing of our drive shaft used during the calculations. Made in AutoCAD*




*We are only showing the gear used in these calculations on the schematic representation above.*

## *Situation 1:*

The SSV accelerates from standstill.

First we'll calculate the Shear force and Bending moment. This was done in maple:

ΣF=0
ΣM=0
We will be using T for the moment of inertia in our calculations.

```
> restart;
> SF:=R1+R2-N2-N1=0;
```

$$SF := R1 + R2 - N2 - N1 = 0 \tag{1}$$

```
> N1:=2.796;
```

$$N1 := 2.796 \tag{2}$$

```
> N2:=2.403;
```

$$N2 := 2.403 \tag{3}$$

```
> SM:=N2*0.047+N1*0.191-R2*0.238=0;
```

$$SM := 0.646977 - 0.238\ R2 = 0 \tag{4}$$

```
> solve(SM,R2);
```

$$2.718390756 \tag{5}$$

```
> R2:=%;
```

$$R2 := 2.718390756 \tag{6}$$

```
> solve(SF,R1);
```

$$2.480609244 \tag{7}$$

```
> R1:=%;
```

$$R1 := 2.480609244 \tag{8}$$

```
>  u := x -> piecewise(  x< 0 , 0 , x >= 0 ,1);
```

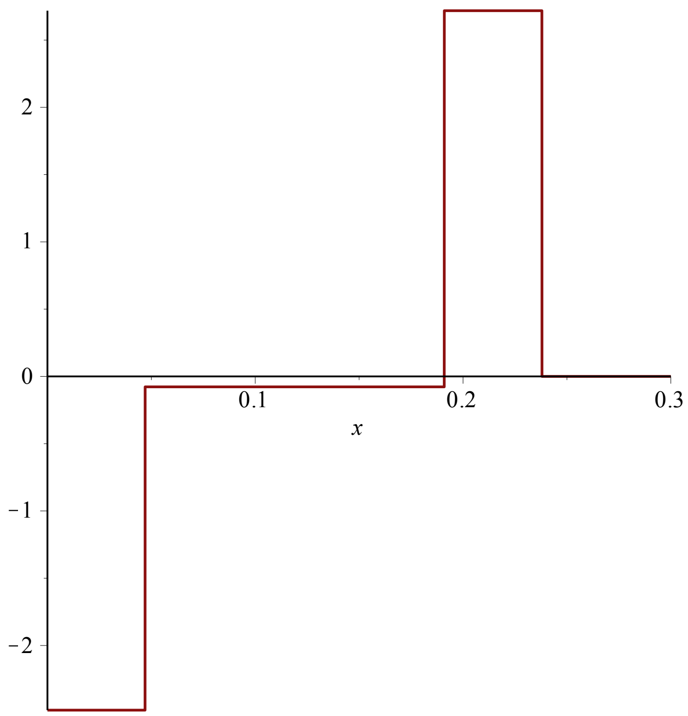
$$u := x \rightarrow piecewise(x < 0, 0, 0 \leq x, 1) \tag{9}$$

```
> fD:=(-R1(u(x)))+(N2*(u(x-0.047)))+(N1*(u(x-0.191)))-(R2*u(x-0.238))
;
```

Distances from "a" to "b", "b" to "d" and "d" to "e" (see added schematic represention of the drive shaft.

$$fD := -2.480609244 + 2.403 \left( \begin{cases} 0 & x < 0.047 \\ 1 & 0 \leq x - 0.047 \end{cases} \right) + 2.796 \left( \begin{cases} 0 & x < 0.191 \\ 1 & 0 \leq x - 0.191 \end{cases} \right) - 2.718390756 \left( \begin{cases} 0 & x < 0.238 \\ 1 & 0 \leq x - 0.238 \end{cases} \right) \tag{10}$$

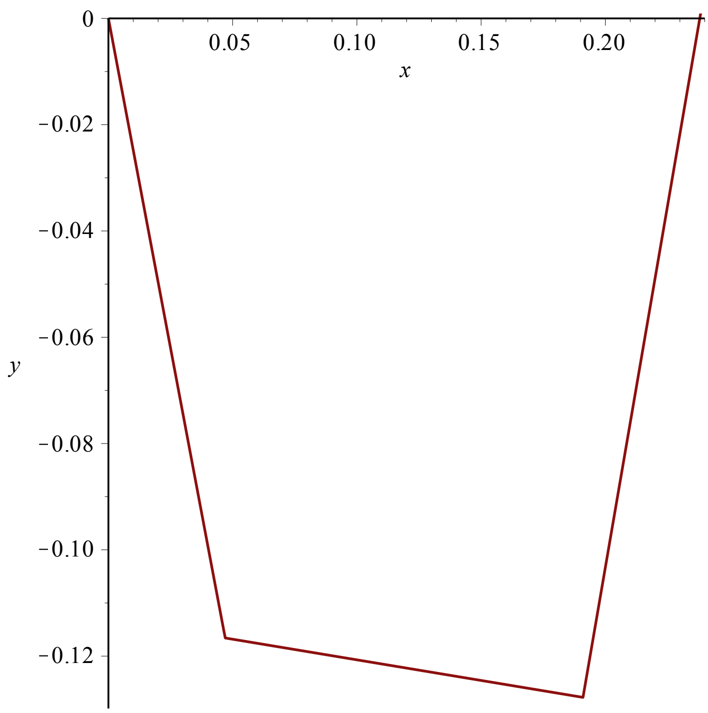
```
> plot(fD,x=0..0.3);
```




```
> M:=(-R1*(x)*(u(x)))+N2*(x-0.047)*u(x-0.047)+N1*(x-0.191)*u(x-0.191)
```
; Distances from "a" to "b", "b" to "d" and "d" to "e" (see added schematic represention of the drive shaft.

$$M := -2.480609244\, x \left( \begin{cases} 0 & x < 0 \\ 1 & 0 \leq x \end{cases} \right) + 2.403\, (x - 0.047) \left( \begin{cases} 0 & x < 0.047 \\ 1 & 0 \leq x - 0.047 \end{cases} \right) + 2.796\, (x - 0.191) \left( \begin{cases} 0 & x < 0.191 \\ 1 & 0 \leq x - 0.191 \end{cases} \right) \quad \textbf{(11)}$$

```
> plot(M,x=0..0.240,y=0..-0.13);
```




Bending moment: This wil be greatest at that point where the moment is largest. So we'll calculate it at this point. At x=0.191.

```
> sigma:=Mmax*y/T;
```

$$\sigma := \frac{Mmax\,y}{T} \tag{12}$$

```
> Mmax:=(-R1*(0.191))+N2*(0.191-0.047)+N1*(0.191-0.191);
```

$$Mmax := -0.1277643656 \tag{13}$$

```
> y:=0.001;
```
//This is half the diameter of our axle.

$$y := 0.001 \tag{14}$$

```
> T:=(Pi*d^4)/64;
```

$$T := \frac{1}{64}\,\pi\,d^4 \tag{15}$$

```
> d:=0.002;
```

$$d := 0.002 \tag{16}$$

```
> sigma;
```

$$-\frac{5.110574624\;10^8}{\pi} \tag{17}$$

```
> sigma:=simplify(%);
```
//MPa or N/m^2

$$\sigma := -1.626746426\;10^8 \tag{18}$$

The minimum tensile strength is about 400 MPa so almost 3 times as high.

The maximum bend is about 163MPa, which is a lot less than the shaft can handle. Additionally, the shaft will only be subjected to this bend for a very short period of time.

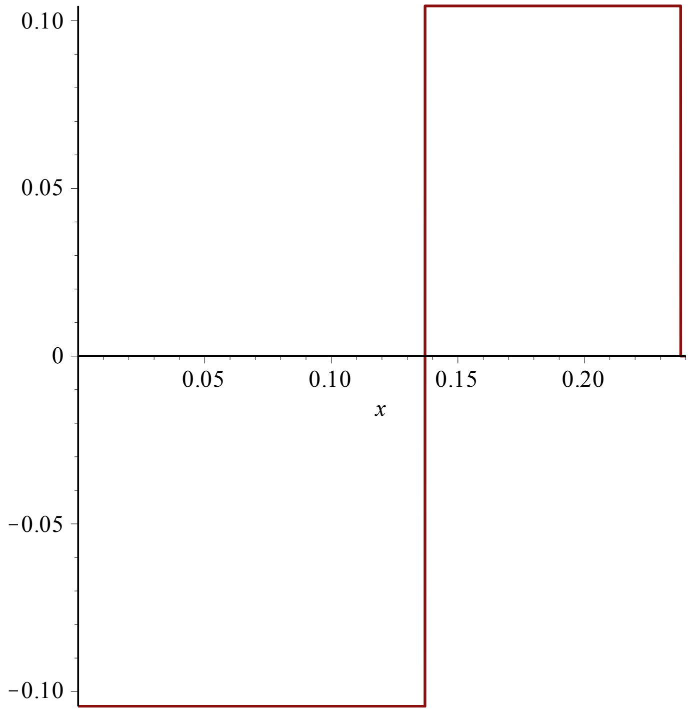
The next maple file shows the calculations of the Torsion:

We'll be using Tp instead of Ip as polar moment of inertia because maple sees I as the imaginairy number.
Tmot2 is Tmot*, meaning the moment from the motor, adjusted by the transmission, on the axle we are investigating now.
rtr and ntr stand for, respectively, the transmission ratio and the transmission loss.

```
> restart;
> m:=0.030;//(kg)
```
$$m := 0.030 \tag{1}$$
```
> rwheel:=0.04;//(m)
```
$$rwheel := 0.04 \tag{2}$$
```
> a:=1.449;//(m/s^2)
```
$$a := 1.449 \tag{3}$$
```
> Tmot:=0.0232; //(Nm)
```
$$Tmot := 0.0232 \tag{4}$$
```
> Jmot:=4.10*10^(-7); //(kg*m^2)
```
$$Jmot := 4.100000000\ 10^{-7} \tag{5}$$
```
> rtr:=1/10;
```
$$rtr := \frac{1}{10} \tag{6}$$
```
> ntr:=0.9;
```
$$ntr := 0.9 \tag{7}$$
```
> VGL:=Tmot2-Tload=((Jmot*ntr)/(rtr^2)+Jload)*alphaload;
```
$$VGL := Tmot2 - Tload = (0.00003690000000 + Jload)\ alphaload \tag{8}$$
```
> Tmot2:=ntr*Tmot/rtr;
```
$$Tmot2 := 0.20880 \tag{9}$$
```
> Jload:=m*rwheel^2;
```
$$Jload := 0.0000480 \tag{10}$$
```
> alphaload:=a*rtr;
```
$$alphaload := 0.1449000000 \tag{11}$$
```
> solve(VGL,Tload);
```
$$0.2087876980 \tag{12}$$
```
> Tload:=%;
```
$$Tload := 0.2087876980 \tag{13}$$
```
> u := x -> piecewise(  x< 0 , 0 , x >= 0 ,1);
```
$$u := x \rightarrow piecewise(x < 0, 0, 0 \leq x, 1) \tag{14}$$
```
> T:=((-Tload/2)*(u(x)))+(Tmot2*(u(x-0.137)))-((Tload/2)*(u(x-0.238)));
```
$$T := -0.1043938490 \left( \begin{cases} 0 & x < 0 \\ 1 & 0 \leq x \end{cases} \right) + 0.20880 \left( \begin{cases} 0 & x < 0.137 \\ 1 & 0 \leq x - 0.137 \end{cases} \right) \tag{15}$$

$$-0.1043938490\left(\begin{cases}0 & x<0.238\\ 1 & 0\le x-0.238\end{cases}\right)$$

```
> plot(T,x=0..0.240);
```




```
> Tmax:=Tmot2-Tload/2;
```

$$Tmax := 0.1044061510 \qquad \textbf{(16)}$$

```
> Torsion:=(Tmax*rshaft)/Tp;
```

$$Torsion := \frac{0.1044061510\ rshaft}{Tp} \qquad \textbf{(17)}$$

```
> rshaft:=0.001;//(m)
```

$$rshaft := 0.001 \qquad \textbf{(18)}$$

```
> Tp:=(Pi*d^4)/32;
```

$$Tp := \frac{1}{32}\pi d^4 \qquad \textbf{(19)}$$

```
> d:=0.002;
```

$$d := 0.002 \qquad \textbf{(20)}$$

```
> Torsion;
```

$$\frac{2.088123020\ 10^8}{\pi} \qquad \textbf{(21)}$$

```
> Torsion:=simplify(%);
```

$$Torsion := 6.646702007\ 10^7 \qquad \textbf{(22)}$$

## *Situation 2.*

In the next situation, the SSV is at maximum speed, so the shaft will be subjected to a smaller Torque. There's no need to redo the shear force and bend moment calculations because they're the same in both situations. The Torsion will be different though:

```
> restart;
```

Second situation: the SSV is at full speed, so the Torsion will be less than when just speeding up.
Tmot*-Tload=((Jmot*ηtr/rtr^2)+Jlload)*αload.
This is the formula to describes the Torque of our SSV. Here we see an acceleation (α). Our SSV is at top speed, so αlast equals zero:
Tmot*=Tload

```
> Tload:=Frr*rwheel;
```

$$Tload := Frr\ rwheel \tag{1}$$

```
> Frr:=Crr*N;
```

$$Frr := Crr\ N \tag{2}$$

```
> N:=m*g;
```

$$N := m\ g \tag{3}$$

```
> g:=9.81;
```

$$g := 9.81 \tag{4}$$

```
> rwheel:=0.04;
```

$$rwheel := 0.04 \tag{5}$$

```
> rwheelf:=0.02;
```

$$rwheelf := 0.02 \tag{6}$$

```
> Crr:=0.0304;
```

$$Crr := 0.0304 \tag{7}$$

We have three wheels, so Tlast equals the sum of the rolling resistance of these three wheels. We'll name them Tl, Tr and Tf. (l=left, r=right, f=front).

```
> Tl:=Crr*ml*g*rwheel;
```

$$Tl := 0.01192896\ ml \tag{8}$$

```
> ml:=0.285;
```

$$ml := 0.285 \tag{9}$$

```
> Tr:=Crr*mr*g*rwheel;
```

$$Tr := 0.01192896\ mr \tag{10}$$

```
> mr:=0.245;
```

$$mr := 0.245 \tag{11}$$

```
> mf:=0.255;
```

$$mf := 0.255 \tag{12}$$

```
> Tf:=Crr*mf*g*rwheelf;
```

$$Tf := 0.00152094240 \tag{13}$$

```
> Tload:=Tl+Tr+Tf;
```

$$Tload := 0.00784329120 \tag{14}$$

```
> Tmot:=Tload;
```

$$Tmot := 0.00784329120 \tag{15}$$

For the calculation of the Torsion on our shaft, we'll divide the delivered torque for Tlast evenly over the two wheels on the shaft.

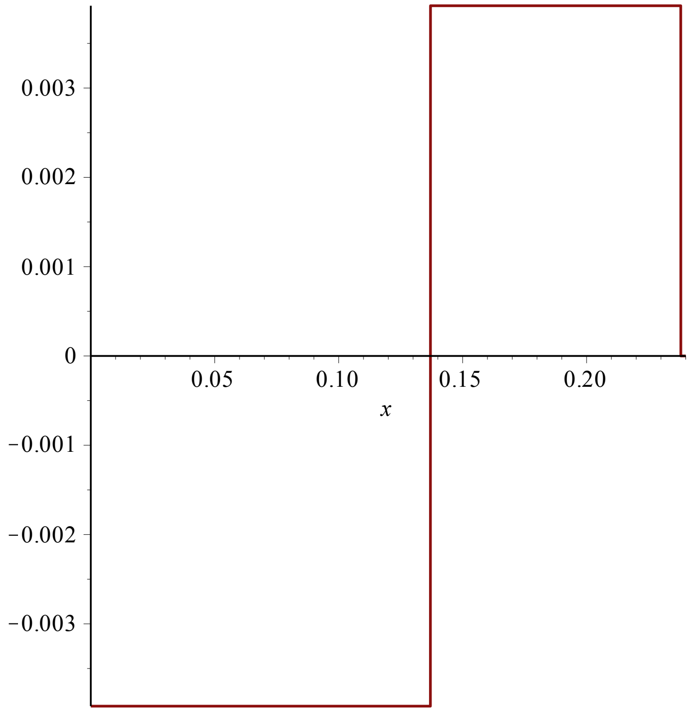
```
> u := x -> piecewise(  x< 0 , 0 , x >= 0 ,1);
```

$$u := x \rightarrow piecewise(x < 0, 0, 0 \le x, 1) \tag{16}$$

```
> T:=((-Tload/2)*(u(x)))+(Tmot*(u(x-0.137)))-((Tload/2)*(u(x-0.238)))
  ;
```

$$T := -0.003921645600 \left( \begin{cases} 0 & x < 0 \\ 1 & 0 \le x \end{cases} \right) + 0.00784329120 \left( \begin{cases} 0 & x < 0.137 \\ 1 & 0 \le x - 0.137 \end{cases} \right) - 0.003921645600 \left( \begin{cases} 0 & x < 0.238 \\ 1 & 0 \le x - 0.238 \end{cases} \right) \quad \textbf{(17)}$$

```
> plot(T,x=0..0.240);
```




```
> Torsion:=(Tmax*rshaft)/Tp;
```

$$Torsion := \frac{Tmax\ rshaft}{Tp} \quad \textbf{(18)}$$

```
> Tmax:=Tload/2;
```

$$Tmax := 0.003921645600 \quad \textbf{(19)}$$

```
> rshaft:=0.001;
```

$$rshaft := 0.001 \quad \textbf{(20)}$$

```
> Tp:=(Pi*d^4)/32;
```

$$Tp := \frac{1}{32}\,\pi\, d^4 \quad \textbf{(21)}$$

```
> d:=0.002;
```

$$d := 0.002 \quad \textbf{(22)}$$

```
> Torsion;
```

$$\frac{7.843291200\ 10^6}{\pi} \quad \textbf{(23)}$$

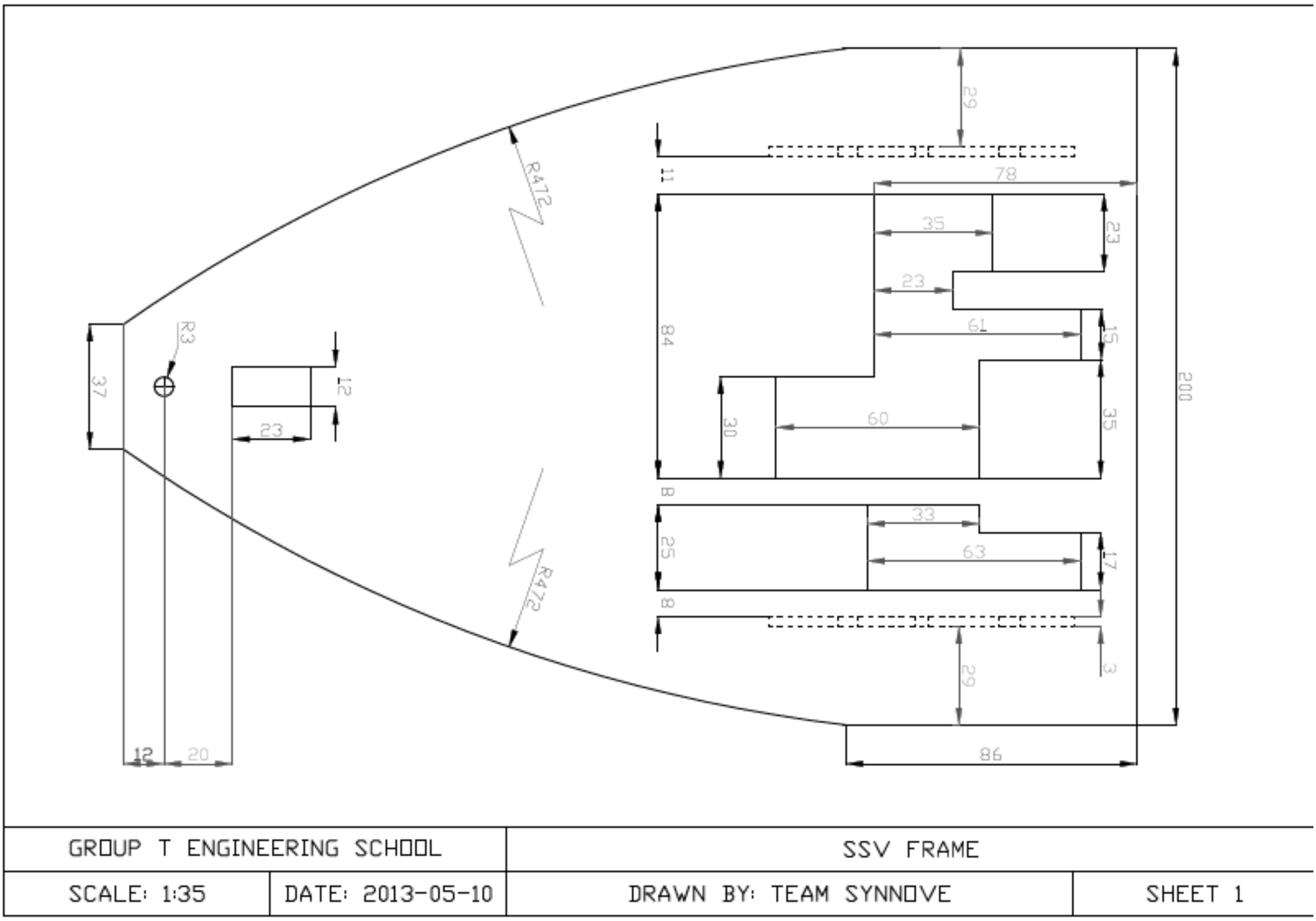
```
> Torsion:=simplify(%);
```

$$Torsion := 2.496597129\ 10^6 \quad \textbf{(24)}$$

From these calculations we can see that the Torsion is almost 30 times smaller at top speed as compared to when the SSV is just starting to accelerate.

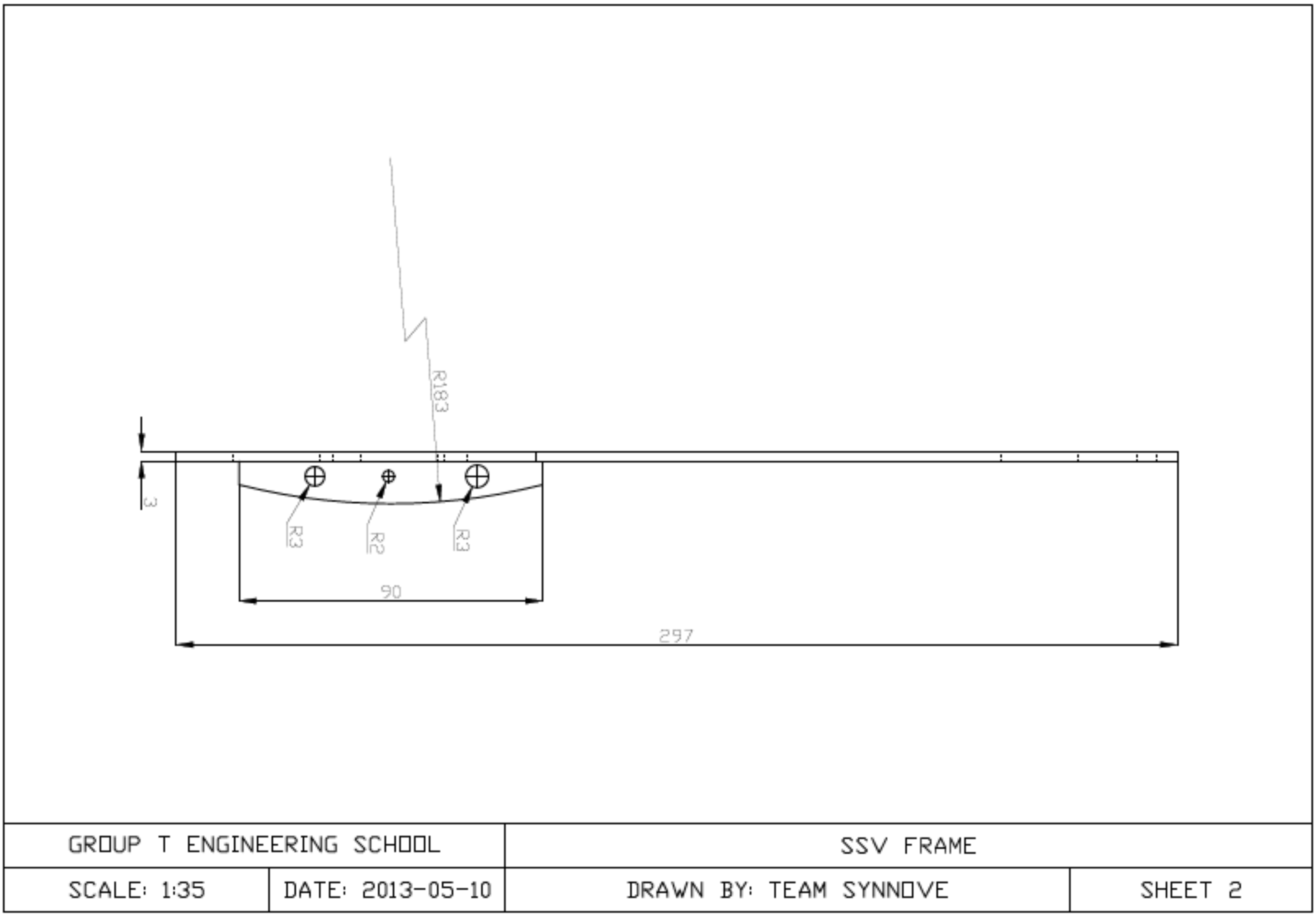
# III. 2D technical drawing

Top-view:




*Technical drawing of the top view.*

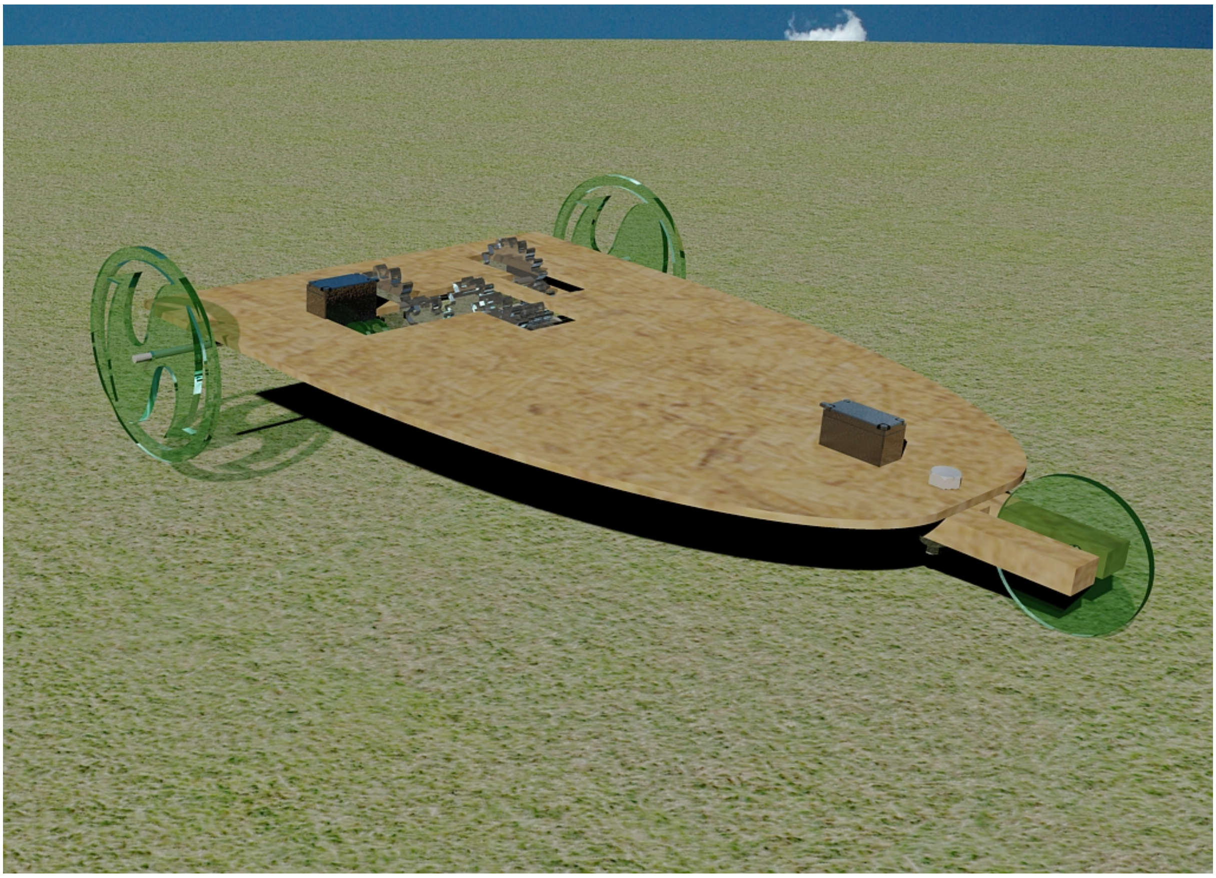
Side view:



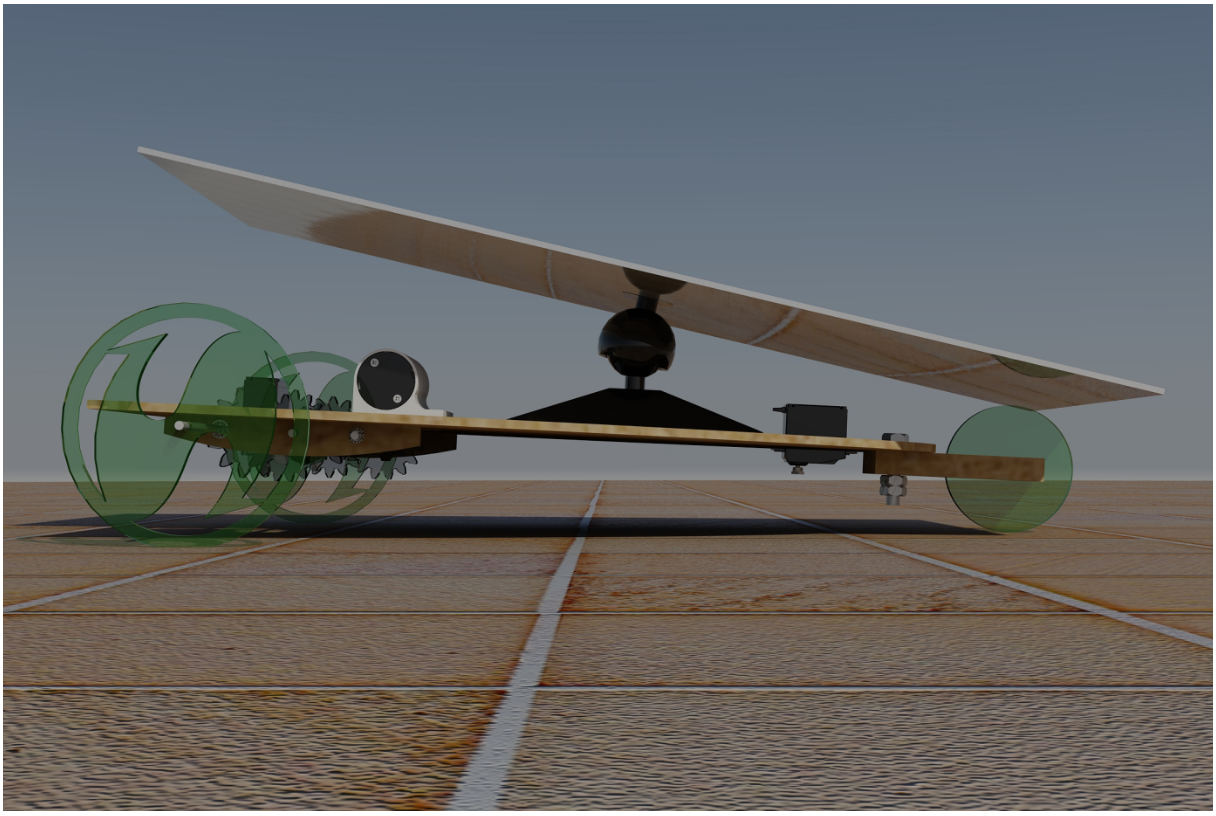

*Technical drawing of the side view.*

When either of the sketches above isn't clear enough, you can see the PDF file on our Wikiversity.

We also made some 3D drawings of our small solar vehicle:



*3D drawing made in AutoCAD, top view, without solar panel.*



*3D drawing made in AutoCAD, side view, with solar panel.*

# IV. Collision

### *Given:*

$V_A$ = 3.7 m/s

$m_A$ = 1.2 kg

e=1

**Asked:** Δt =?

### *Solution:*

$V_{A,c}$ = the speed on the collision axle before the collision

$V_{A,c}$ = 3.7 sin 16° = - 0.64 m/s

$V_{A,c}'$ = the speed on the collision axle after the collision

e=1 because it is an elastic collision

$$e= \frac{-(V_{B,c}' - V_{A,c}')}{V_{B,c} - V_{A,c}} = 1$$

$V_{B,c} = V_{B,c}'$ = 0 because the body B is the wall here and it doesn't move before or after the collision.

If we fill in these values:

$$1=\frac{-(0- V_{A,c}')}{0-0.64}$$

we find a $V_{A,c}'$ = 0.64 m/s.

If we make the body free:

$$L_{A,c}' - L_{A,c} = \int_0^t < F > dt$$

<F> =10

The impulse is $L_{A,c} = m*V_{A,c}$ = 1.2 * 0.64 = 0.768 $\frac{kg*m}{s}$

If we fill in everything in the equation, we find: 1.2 * (0.64-(-0.64)) = 10 * t

So we find that Δt should be at least 0.154 seconds.

## V. Exercise: biker

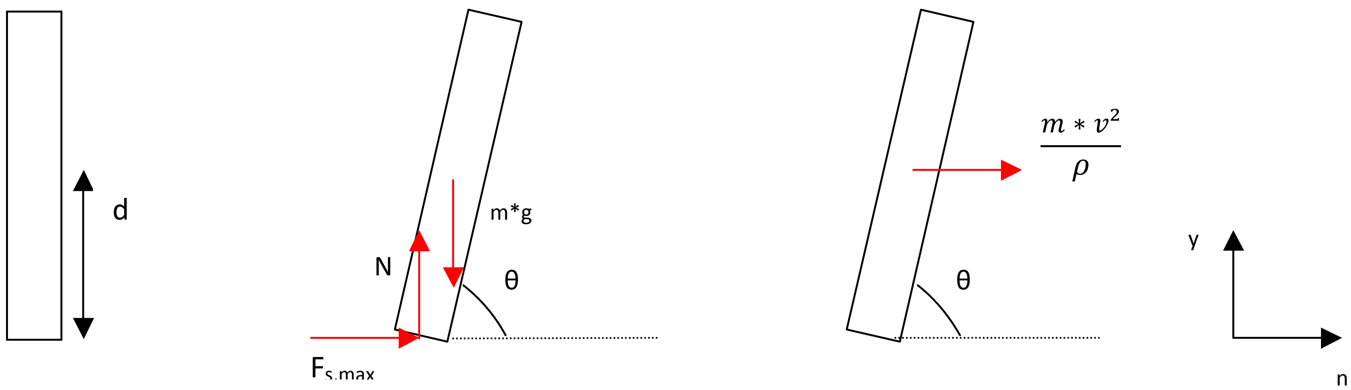
### *Given:*

*A cyclist is riding at a speed of 50 km/h. He arrives at a crossroad and needs to turn left. The radius of the turn is 10 m. What is the necessary inclination angle? Does he have to reduce his speed to make a safe turn? What is the maximum possible speed?*

*Mass of the cyclist: 60 kg; mass of the bicycle: 12 kg; distance between ground and center of Gravity: 1,5 m (when he is riding vertically); Static coefficient of friction between wheels and ground: 0,3.*

**Asked:** $v_{max}$ =?, θ=?

### *Solution:*




**<u>ΣF<sub></sub></u>**

**$\Sigma F_y$= ...**

$$-m * g + N = 0 <=> N = m * g$$

<=> N = (60kg + 12kg) * 9,81 Newton/Kg = 706,32 Newton

$$Fs,max = \mu s * N <=> Fs,max = \mu s * m * g$$

<=> $Fs,max = 0{,}3 * 72\text{kg} * 9{,}81 \frac{\text{Newton}}{\text{Kg}} = 211{,}896\ Newton$

**$\Sigma F_n$= ...**

$Fs,max = (m * v^2)/\rho$ with $Fs,\max = \mu s * m * g$

<=> v = $\sqrt{\mu s * \rho * g}$ = $\sqrt{0{,}3 * 10\ m * 9{,}81\ N/kg}$ = 5,424 m/s.

**$\Sigma M_A$= ...**

m * g * d * cos(θ) = d * sin(θ) * $(m * v^2)/\rho$ <=> $\cancel{m}$ * $\cancel{g}$ * $\cancel{d}$ * cos(θ) = $\cancel{d}$ * sin(θ) * $\cancel{m}$ * $\cancel{g}$ * μs

<=> tan(θ) = $\frac{1}{\mu s}$ = 3,33

<=> θ = 73,28°